UPC 061

Fermilab

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January 5, 1979

TEST OF LCP2 INSIDE QB6

I. DESIGN

LCP2 is a long correcting pack. Each coil (octopole, sextupole, dipole) is made up of two layers and the whole pack is banded with two Kapton tape layers. The pack was put inside QB6 where it was slightly shifted from its actual position for magnetic measurements. The tests were done in Lab 5 between December 29 and January 4.

II. QUENCH BEHAVIOR

The necessity of a strong banding appears as the external field is increased (Fig. 1):

- without external field, the maximum currents are almost the same as with LCP1 (which had a one layer aluminum banding).

- as the external field is increased the percentage of critical current which can be reached decreases, the more so as the coil is closer to the external face of the pack. With the external field the quench occurs at a constant level of magnetic force for each coil.

III. MAGNETIC MEASUREMENTS

Magnetic measurements were made in the body part of the pack, without external field. Roughly, the results are as expected for the octopole and the sextupole and are quite bad for the dipole.

a. Magnetic strength: for a current of 50A, the field at one inch in the body part is:

0.047T for the 8P (expected value: 0.043T)
0.064T for the 6P (expected value: 0.066T)
0.134T for the 2P (expected value: 0.149T)

b. Magnetic homogeneity in the body part: ratio of harmonic modulus to fundamental modulus at one inch:

HARM. \ FUND.	OCTOPOLE	SEXTUPOLE	DIPOLE
Quadrupole	-	-	0.174
Sextupole	-	1	0.121
Octopole	1	2.8 E-2	5.9 E-2
10P	1.0 E-2	2.0 E-3	9.1 E-27
12P	5.0 E-3	1.1 E-2	4.0 E-3
20P	4.0 E-4	5.0 E-4	1.0 E-3

continued

IV. CONCLUSIONS OF THIS TEST

1. A strong banding is needed for using the pack in the external field of the QB.

2. The winding and the assembly of the dipole coils must be much more accurate.

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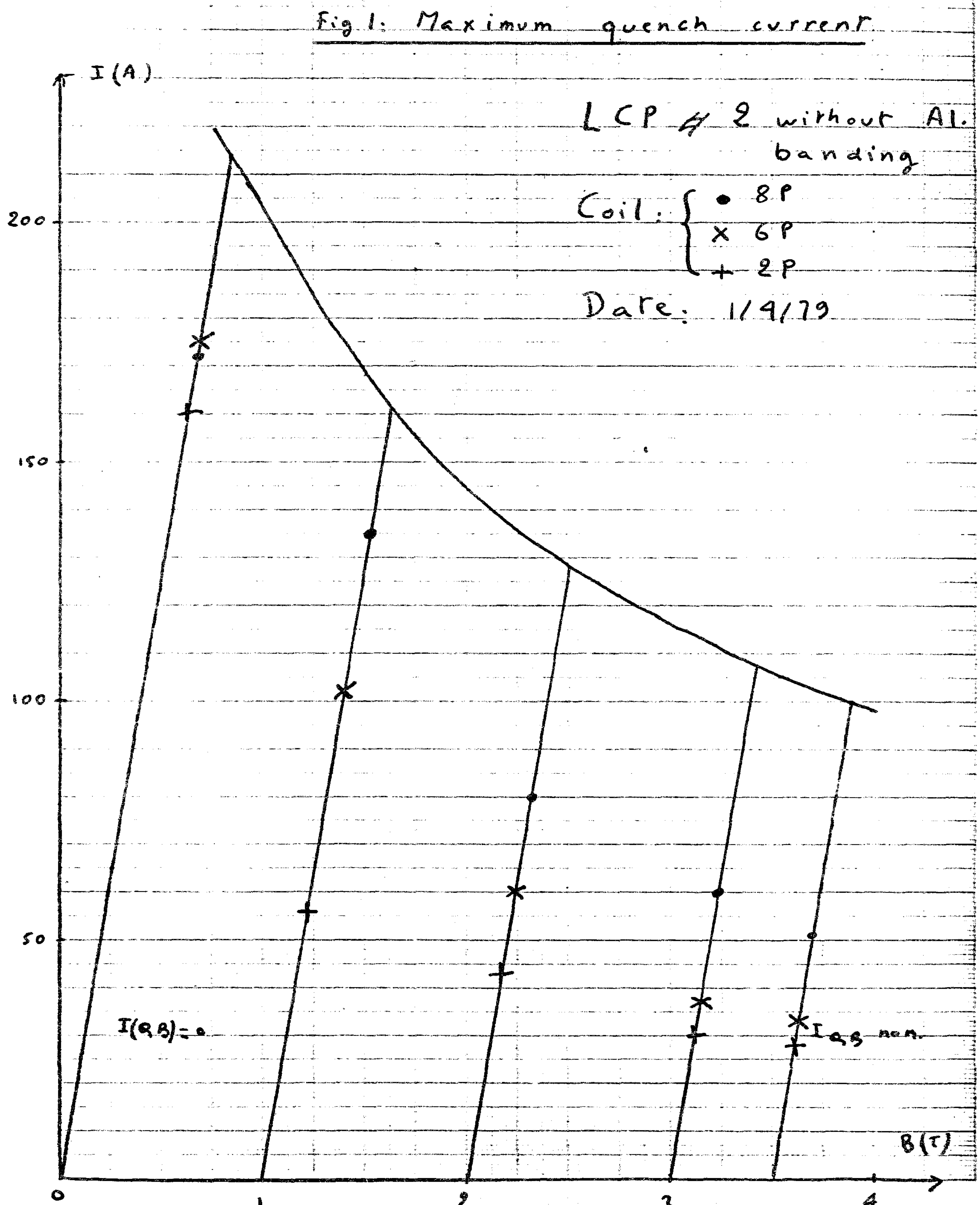
Fig 1: Maximum quench current
I (A)
LCP # 2 without Al. banding
Coil: 8P
6P
2P
Date: 1/9/79
200
150
100
50
I(Q B) = 0
I QB nom.
B(T)
0
1
2
3
4

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PARAMETERS OF THE LONG TUNE QUADRUPOLE (LQT)

A few changes have been made in the initial tooling for LQT; this is an updated memo.

Theoretical Parameters:

PARAMETERS	INNER COIL	OUTER COIL	IRON
Inner Diameter	4.108"	4.342"	4.56"
Outer Diameter	4.342"	4.50"	5.56"
Number of Layers	6	4	-
Number of Turns	372	124	-
Starting Angle	0.1°	0.1°	-
Final Angle	35.9°	18°	-
Total Length	≤10"	≤10"	≤10.12"

The theoretical design enables us to cancel the 12th and 20th harmonics in the body part. Both coils are wound without stopping

Expected Values:

Magnetic length ≥8.8"
Nominal strength (52 kG inch at 1") for I≈57A
Integrated homogeneity adjusted with the angles of both coils.

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STRENGTH OF THE LONG CORRECTING COILS

This is an updated memo with the actual winding. The following hypotheses are taken for each coil:

- two layer coils, angles of a sector as to cancel the first allowed harmonic (i.e., 60° for dipole, 20° for sextupole, 15° for octopole)
- magnetic length = 66 inches
- current density calculated with the number of turns per sections we are now winding:

  41 turns for octopole (2 sections)
  57 turns for sextupole (2 sections)
  88 turns for dipole (1 section)

- nominal current of 50 A

The magnetic field produced by thin coils with constant current density between the angles 0 and $\frac{\pi}{3N}$ is:

$$B_N = \mu o \, J_O \, \Delta R \, \frac{\sqrt{3}}{\pi} \left(\frac{r}{R}\right)^{N-1}$$

where N = half number of pole (1 for dipole, 3 for sextupole.)
J_O = mean current density
ΔR = thickness of the coil

Assuming that N_T is the number of turns per sector, for a two layer coil:

$$J_O = \frac{2N_T \, I}{\frac{\pi}{6N} \, (R_2{}^2 - R_1{}^2)} \simeq \frac{6N \, N_T \, I}{\pi \, \Delta R \, R}$$

so $$B_N = \frac{6\sqrt{3} \, \mu o}{\pi^2} \, \frac{N \, N_T \, I}{R} \left(\frac{r}{R}\right)^{N-1}$$

continued

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Numerical Application:

We have

	N	N_T	R
Octopole	4	20.5	1.4~~8~~" 6
Sectupole	3	28.5	1.50"
Dipole	1	88	1.54"

so, at r = 1":

$$B_1 = 0.149 \text{ T}$$
$$B_3 = 0.066 \text{ T}$$
$$B_4 = 0.043 \text{ T}$$

Assuming a magnetic length of 66 inches, the strength of each coil is:

$$\int B_1 \, d\ell = 98.2 \text{ kG inch}$$

$$\int B_3 \, d\ell = 43.5 \text{ kG inch}$$

$$\int B_4 \, d\ell = 28.6 \text{ kG inch}$$

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TEST OF LQT-1

LQT-1 is the first 10" long trim quadrupole. It was tested on February 8 in Lab 5 (helium bath).

I. TRAINING

The coil has shown training although we tried to reduce it by pulsing a small current during cooldown.

Quench #	I Quench (A)	dI/dt (A/sec)
1	52	10
2	54	10
3	60	2
4	65	1
5	68	1
6	70	1
7	71	1
8	74	1
9	75	1
10	80	10
11	85	1
12	86	2
13	89	10
14	90	10

The maximum current reached (90A) is about 75% of the critical current along the load line (see Fig. 1).

The coil did not show any degradation when ramped between 1A/sec and 40A/sec.

II.-1. INTEGRAL STRENGTH

Its value vs. the current is lower than expected:

Current (A)	$\int B_{quad} dl$ at 1" (kg inch)	Transfer Function (kg inch/A)
25.1	19.4	0.773
38.1	29.7	0.769
50.0	38.5	0.767
62.9	47.1	0.748
74.8	53.7	0.718

Cont'd.

With the present design, a current of 71A is needed to get the nominal value of 52 kg inch. The deduced magnetic length from these results is 7.4 inches (at 50A). The reason for getting a shorter magnetic length than expected is the random winding which does not enable to get the theoretical shape of the body as the number of turns increases.

Without changing the body design the following total length of the coil can be deduced to reach the nominal value of 52 kg inch:

11.2" for a current of 60A.

12.6" for a current of 50A.

II.-2. FIELD HOMOGENEITY

Value of $\frac{\int B_N dl}{\int B_{quad} dl}$ at 1" for 50A and 75A:

N	50A	75A
Sextupole	3.0 E-3	3.6 E-3
Octopole	2.1 E-3	2.2 E-3
Decapole	3 E-4	4. E-4
12 Pole	5.6 E-3	7.0 E-3
20 Pole	2 E-4	2. E-4

The integral field and the magnetic homogeneity show some iron saturation effects.

III. PROTECTION

The effect of the voltage threshold and the value of the dump resistance on the current decay after a quench were studied:

τ is such as $I(\tau) = \frac{I_{max}}{e}$

$\bar{R}_i$ is such as $\tau = \frac{L}{R_d + R_i}$ (L = 250mH)

$\int I^2 dt = I^2_{max} \frac{\tau}{2}$

All the quenches were around 90A (W_s #1kJ)

Cont'd.

R Dump (Ω)	Threshold (V)	τ (m sec)	$\bar{R_i}$ (Ω)	$\int I^2 dt$ (A^2 sec)
0.4	0.35	140	1.4	540
0.4	3.5	160	1.2	610
0.2	0.35	150	1.5	570
0.2	3.5	140	1.8	540
0.1	0.35	140	1.7	540
0.1	3.5	140	1.7	540
0.	0.35	140	1.8	540
0.	3.5	140	1.8	540

The results show that:

- the coil is self-protected and does not need any dump resistance.
- the voltage threshold can be put at a high level.
- the maximum temperature during a quench is around 50K.

IV. CONCLUSIONS OF THE TEST

- Training still to improve.
- Which way to be chosen to reach the nominal strength?
- Is magnetic homogeneity good enough?
- Take into account the results about protection for actual scheme.

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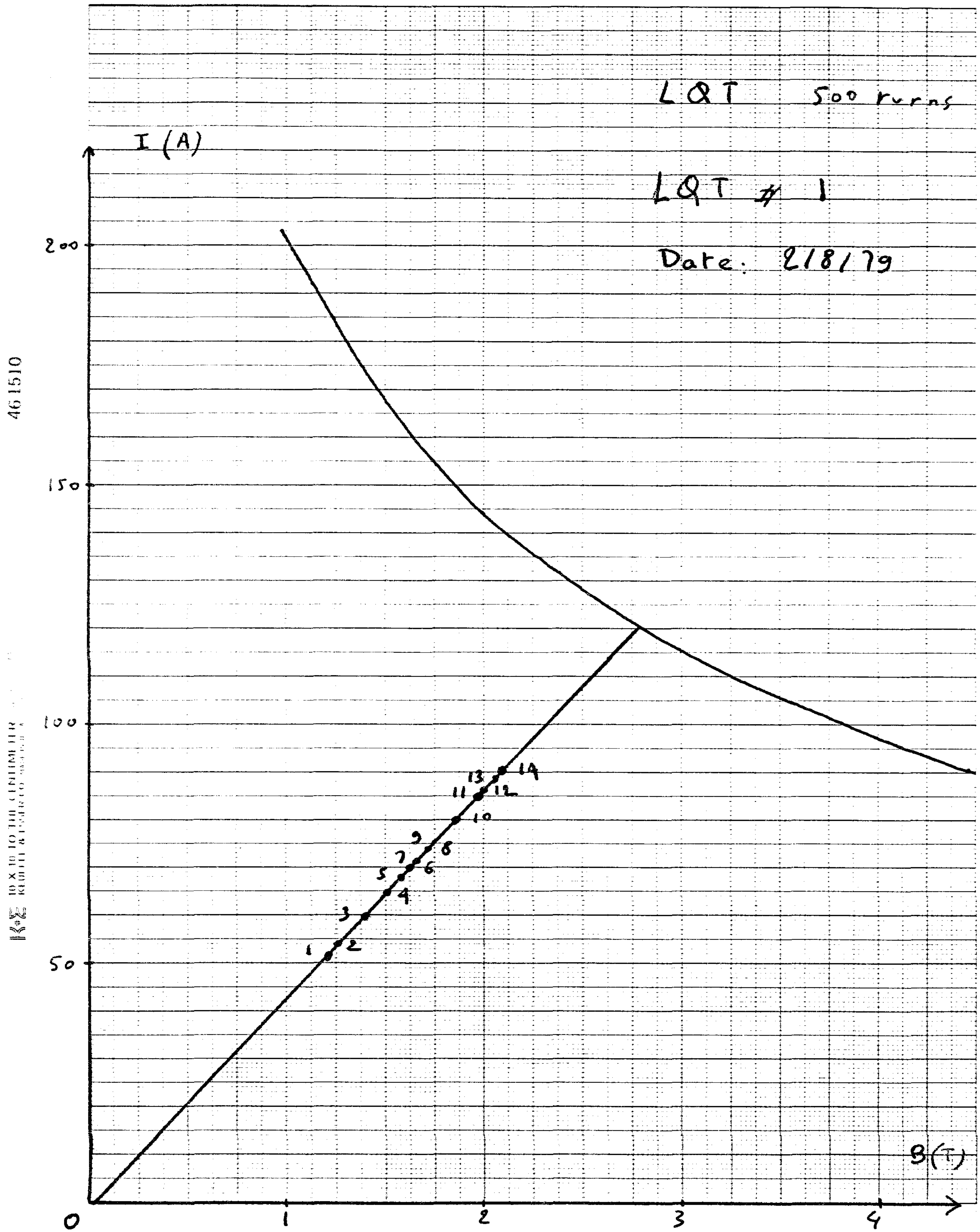
LQT 500 turns
LQT # 1
Date: 2/8/79
I (A)
200
150
100
50
0
1
2
3
4
B (T)
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Figure 1.